ζ Orionis A is a Double Star

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ABSTRACT

A close, $4^{\rm th}$ magnitude companion to ζ Orionis A has been resolved with the Navy Prototype Optical Interferometer at the Lowell Observatory. This confirms an indication of multiplicity from observations with the stellar intensity interferometer at Narrabri 26 years ago. The new component in the multiple system ADS 4263, ζ Orionis Ab, is two magnitudes fainter than Aa, which is a supergiant of type O9.5. During February and March of 1998, the pair had a mean separation of 42 mas. Orbital motion was subsequently detected, but the corresponding arc allows only a preliminary ephemeris.

Subject headings: binaries: visual — stars: individual (ζ Orionis) — techniques: interferometric

1. Introduction

O supergiants are extraordinary in their rarity, extreme physical parameters, and effect on the surrounding interstellar medium. Binaries are common among O stars in clusters and associations (Mason et al. 1998). Being a member of the Orion OB1 association, ζ Orionis A is no exception, showing companions B at 2.4 arcseconds and C at 57 arcseconds. We report in this paper the first resolved images of another close companion to component A at a mean separation of some 45 milli-arcseconds (mas). Significant orbital motion has been detected over the course of a year, and thus provides for a special opportunity to measure the physical parameters of the bright ($V = 2$) O9.5 supergiant primary and its companion and to perform long term detailed studies with moderate size telescopes.

Hanbury Brown et al. (1974) first reported that ζ Orionis A was clearly not a single star based on a zero-baseline correlation coefficient significantly below unity obtained with the intensity interferometer at Narrabri. They estimated a magnitude difference of about 2 mag. Many subsequent spectroscopic (e.g. Bohannan & Garmany 1978; Levato et al. 1988) and speckle interferometric observations (e.g. Mason et al. 1998) have not shown definitive evidence of a close companion. Hartkopf (1998, personal communication) reports that CHARA speckle interferometry at a resolution limit of 0.030 arcsec did not resolve component A in five observations over the interval 1983 through late 1994.

The observations reported here were made with the Navy Prototype Optical Interferometer at Lowell Observatory (NPOI, Armstrong et al. 1998). Optical long baseline interferometry has enabled the direct detection of stellar companions as close as a few mas. The resolving power of optical interferometers is directly proportional to the length of the baselines used, and is independent of the effects of atmospheric turbulence as long as the fringes can be detected within their coherence time. Early interferometers only measured the visibility amplitude (i.e., the fringe contrast) on one baseline at a time, requiring simple stellar models to be fit to the data (see, e.g., Hummel et al. 1995). With the advent of multiple station interferometers (Armstrong et al. 1995), the visibility phase can be recovered by forming the complex triple product of the visibility along triangles of baselines, thus removing atmospheric phase perturbations and allowing the application of aperture synthesis algorithms in order to obtain images of stars (Baldwin et al. 1996; Benson et al. 1997).

2. Observations and data reduction

The array setup was as described by Benson et al. (1997) and included three simultaneous baselines between 18 m and 38 m, and fringe detection in 20 channels between $\lambda\lambda$ 520 nm to 850 nm. The observing schedule provided for repeated observations of the program star and a nearby calibrator (i.e., a single, unresolved star, here ϵ Orionis). The data were edited and averaged over the length of a scan, typically 90 s. The program star visibility amplitudes were normalized with the amplitudes of the calibrator, which should equal unity in the absence of atmospheric turbulence and instrumental effects. The same procedure was used for the closure phases (the phases of the visibility triple product), which should equal zero for the calibrators in the absence of path length inequalities in the beam combiner. In so doing, we assume that program and calibrator star, if they are sufficiently close together on the sky, have been affected in the same way by the atmosphere and the instrument. The NPOI data reduction is described in more detail by Hummel et al. (1998). The dates of observation and the number of visibility measurements obtained (all 20 channels combined) are given in Table 1.

3. Imaging

We used standard hybrid imaging software (AIPS), originally developed for VLA/VLBI, to produce the maps shown in Fig. 1. The algorithm combines image deconvolution for aperture synthesis data and self-calibration for phase closure data to iteratively approach an image solution consistent with the data as determined by computing the model visibilities from the map by Fourier transformation. Since the structure of a double star is so simple, this algorithm converges quickly.

4. Modeling

We have modeled the visibility data with a pair of nearly unresolved stellar disks, adjusting the magnitude difference in the V, R, and I bands, as well as the parameters of a Keplerian orbit. Due to the small orbital phase coverage, we refrain from publishing the elements, but give a preliminary ephemeris for the year 2001 in Table 2. The orbital period used for the ephemeris is 7.6 years. We show the observed arc in Fig. 2.

The secondary, Ab, is 2.0 magnitudes fainter than the primary Aa with almost no dependence on the spectral band. Based on the combined $(R-I)$ color index of component A and the individual apparent V magnitudes for Aa and Ab, we estimate that the stellar disks are nearly unresolved at less than 0.6 mas. This is consistent with the intensity interferometer measurements of a 0.48 mas diameter (Hanbury Brown et al. 1974). For future orbit determinations, we list in Table 1 the results of fitting each night's data with separation and position angle of the binary, keeping the component parameters fixed. Columns 1 and 2 give date and fractional Julian year of the observation (at 7 UT), column 3 the number of measured visibilities, column 4 the baseline if only a single one was in use, columns 5 and 6 the derived separation and position angle, columns 7 to 9 the semi-axes and the position angle of the uncertainty ellipse, and column 10 the deviation of the fitted relative binary position (ρ, θ) from the model values. Position angles are measured counterclockwise from north. Note that the very elongated positional uncertainty ellipses correspond to nights where only one baseline was in use over a limited range of hour angles.

5. Discussion

Also known as HR 1948/1949, ADS 4263, HIP 26727, HD 37742/3, ζ Orionis is a multiple system with components B ($V = 4.2$) at a position angle of 164.5 degrees 2.3 arcseconds to the south of A, and C ($V = 9$) at a position angle of 10 degrees 58 arcseconds to the north (Abad et al. 1998; Mason et al. 1998). Component Aa is a supergiant of type O9.5 ($V = 2.0$). Since the secondary Ab is about the same color as the primary, but 2 magnitudes fainter, it must be a dwarf of type late O. The Hipparcos catalogue (ESA 1997) lists a parallax of 3.99 ± 0.79 mas, but the astrometric solution did not detect (and therefore account for) the presence of Ab. Assuming component masses of 28 $\mathcal{M}_\odot$ and 23

$\mathcal{M}_\odot$ for primary and secondary, respectively (Schmidt-Kaler 1982), we expect velocity semi-amplitudes of about 20 km/s and 24 km/s.

The significance of the discovery of another component in ζ Orionis becomes apparent in the context of the formation of massive stars (e.g. Bonnell et al. 1998) and the rate of multiplicity found among O stars (e.g. Mason et al. 1998). Furthermore, by reporting these data before a definitive orbit is determined, possibly in several years time, we hope to focus attention on the need to possibly re-interpret various studies of this star, e.g. in the fields of hot star photospheres (Voels et al. 1989), comparisons with stellar models (Runacres & Blomme 1996), and effects on the interstellar medium around ζ Orionis (Jenkins & Peimbert 1997).

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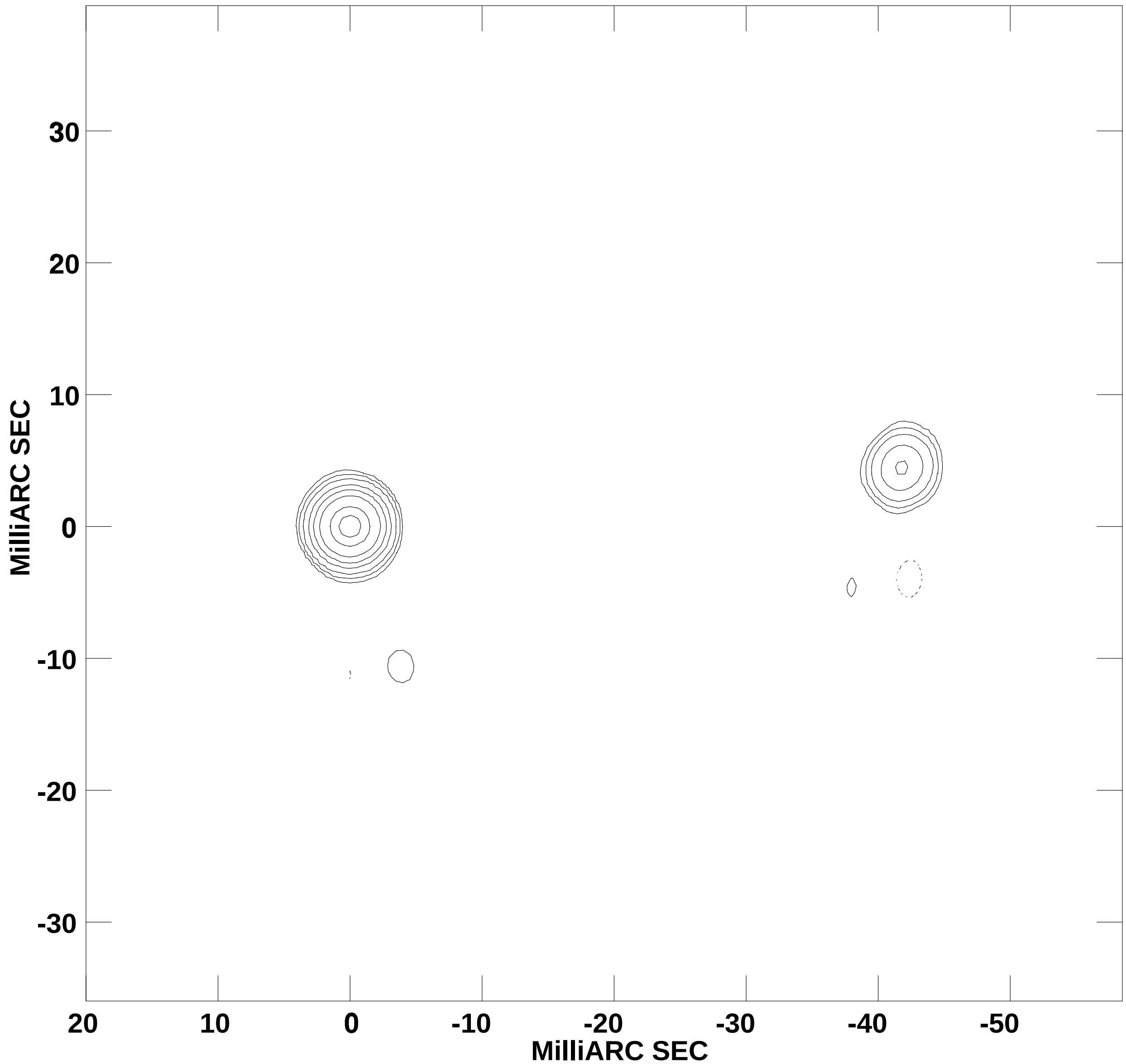
Table 1. Observation and result log

UT Date	Julian Year	Number of visibilities	Baselines	ρ (mas)	θ (deg)	$\sigma_{\rm maj}$ (mas)	$\sigma_{\rm min}$ (mas)	φ (deg)	O–C (mas)
Feb 13	1998.1185	475		42.05	276.19	0.053	0.017	174.7	0.121
Feb 14	1998.1213	380		42.04	276.38	0.078	0.022	175.6	0.312
Mar 02	1998.1678	570		42.55	275.12	0.127	0.020	174.9	0.236
Mar 20	1998.2144	380		42.97	273.98	0.069	0.016	175.8	0.253
Nov 19	1998.8824	95	EW	46.93	261.05	1.797	0.076	163.5	1.835
Nov 26	1998.9016	249		46.81	258.39	0.143	0.040	178.2	0.058
Feb 13	1999.1178	272	CW	47.29	254.55	0.944	0.061	154.9	0.485
Feb 16	1999.1288	119	CW	47.16	253.57	1.027	0.068	154.9	0.183
Feb 18	1999.1315	119	CW	47.27	254.57	1.375	0.139	153.2	0.712
Feb 23	1999.1452	344		47.01	253.83	0.127	0.048	176.1	0.329
Mar 29	1999.2383	258		46.96	252.25	0.122	0.063	179.2	0.581
Mar 30	1999.2410	258		46.98	251.82	0.484	0.130	176.8	0.280

Table 2. Preliminary ephemeris for the 1st of each month in the year 2001

ρ [mas]	θ [deg]
27.8	199.0
26.3	193.8
25.0	188.5
23.6	182.0
22.4	175.0
21.4	167.0
20.7	158.6
20.2	149.4
20.1	140.0
20.3	130.9
20.8	121.8
21.5	113.5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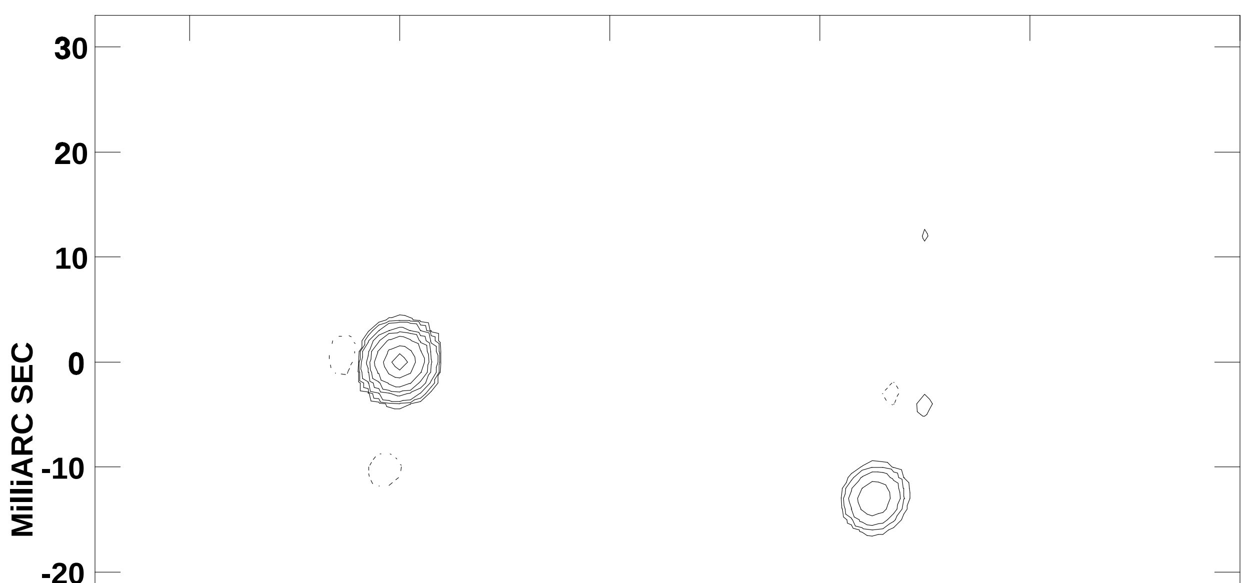
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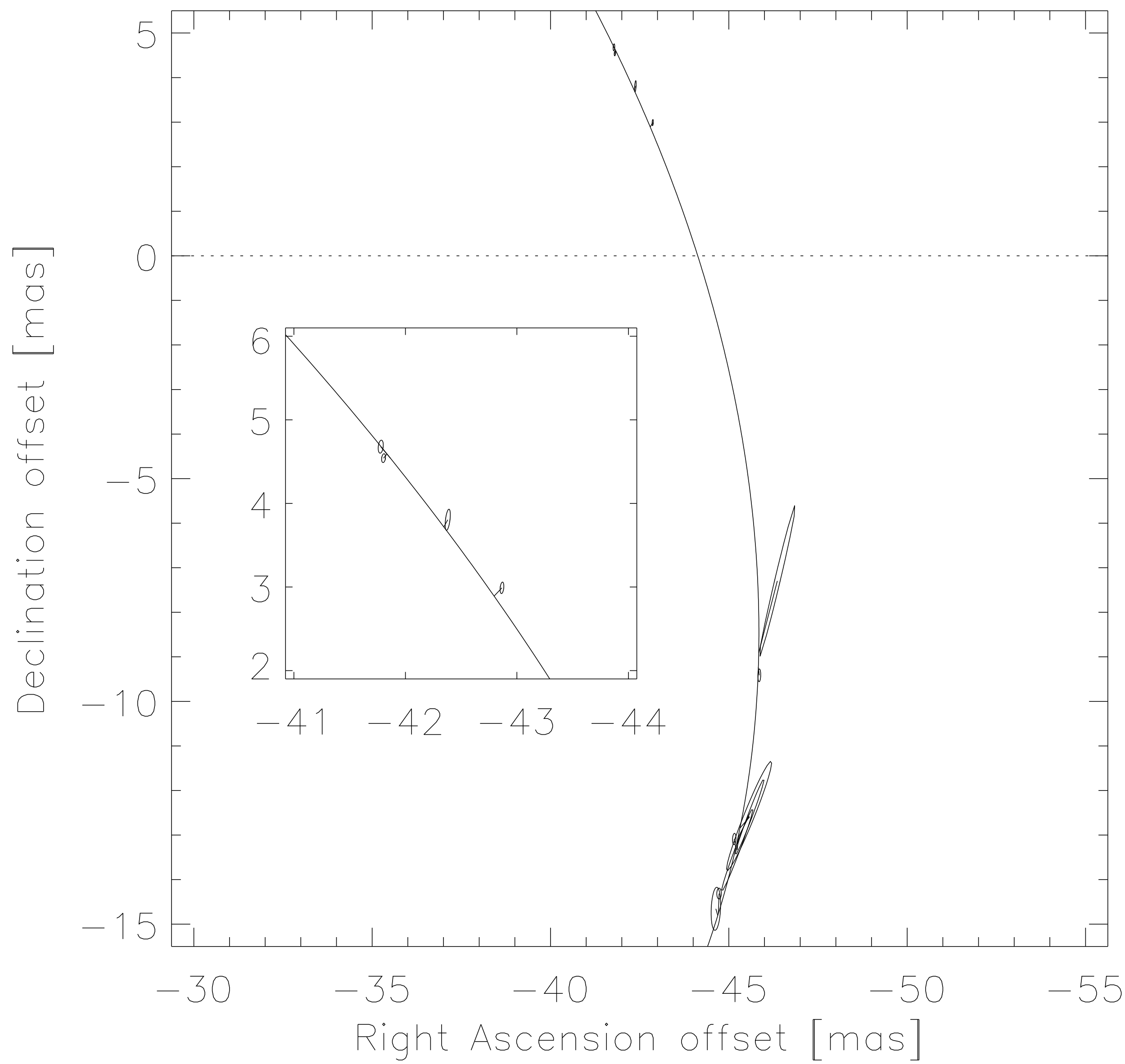

Fig. 2.— The apparent orbit (precessed to epoch J2000). Please note that the observations of early 1998 are repeated in the enlarged inset.